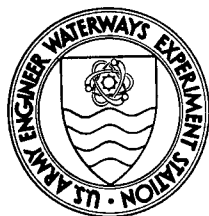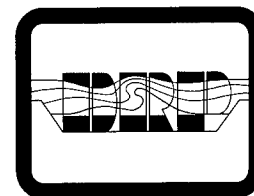19941214 089
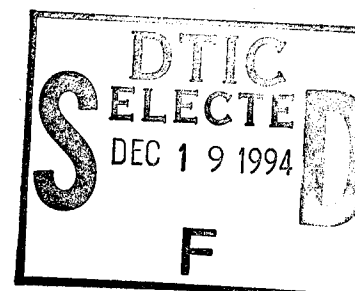
*D*redging *R*esearch
Technical Notes

The PLUme MEasurement System (PLUMES): Operational and Data Processing Procedures for Deep-Water Monitoring

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Purpose

This technical note describes the operational and data analysis procedures for deep-water monitoring of dredged material disposal operations using the PLUme MEasurement System (PLUMES). The development plans for PLUMES and some preliminary field results are described in *Dredging Research Technical Notes* DRP-1-06 (Kraus and Thevenot 1992). Another of the *Dredging Research Technical Notes* (DRP-1-16, Tubman 1994) describes the system that was developed, discusses its commercial availability, and examines the theoretical relationship between PLUMES measurements and suspended sediment concentrations.

Background

During dredging and dredged-material disposal operations, clouds or plumes of suspended sediment are produced at the sites of these operations. The temporal and spatial distribution of turbidity from these plumes, and the fate of the suspended sediment in them, are important environmental concerns. PLUMES was developed to make measurements that provide quantitative information on these factors. The primary instrument of PLUMES is a five-beam Broad-Band Acoustic Doppler Current Profiler (BBADCP), which measures currents and acoustic backscatter intensity. The acoustic backscatter intensity measurements made by the fifth beam provide information about the amount of sediment suspended in the water column. Other instruments composing PLUMES are a conductivity, temperature and depth (calculated from pressure measurements) recorder, commonly referred to as a CTD, and an optical backscatter sensor (OBS).

In September 1993, PLUMES was successfully used to monitor 10 disposal operations in deep water at a disposal site approximately 80 km offshore of San Francisco, CA. Profiles of suspended sediment plumes were made to a maximum depth of approximately 800 m. For this operation, the PLUMES instruments were installed in a towed vehicle, as described in *Dredging Research Technical Notes* 1-16.

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Preliminary results from a PLUMES study conducted off Mobile, AL, are discussed in *Dredging Research Technical Notes* DRP-1-06. Under a contract through the Dredging Research Program (DRP), these data were further analyzed, and the results have been published (Ogushwitz 1994). Under the DRP, a laboratory calibration of a PLUMES was performed (see Lohrmann and Huhta, in preparation). The results of the laboratory calibration and the work of Ogushwitz (1994) have been incorporated in a suite of software programs for postprocessing PLUMES data. The software and its application to the data from the San Francisco site are discussed in this technical note.

Additional Information

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Operational Procedures

In September 1993, PLUMES was used in its deep-water configuration and towed at depth at a location approximately 80 km offshore of San Francisco in 3,000 m of water. In the deep-water configuration, the PLUMES instruments are mounted in a towed vehicle (see Figure 1). Ten disposal operations were monitored by towing the system behind the ship, generally at depths between 10 and 450 m. (Each disposal operation consisted of a scow releasing 1,000 to 2,000 cu yd (765 to 1,530 cu m) of dredged material.) After one release the ship was stopped, and the towed vehicle was lowered in a plume to a maximum depth of approximately 800 m. Plumes from the releases were monitored from 3 to 6+ hr.

Even in rough weather, with waves up to 5 m, PLUMES towed stably and produced good-quality acoustic data. Plumes with horizontal extents of 100 to 2,100 m were tracked. These plumes were monitored by crossing back and forth perpendicular to the current for distances of approximately 1,000 to 2,500 m. The crossings were spaced approximately 1,000 m apart along the axis of the plumes' trajectory.

Navigation was accomplished using a Differential Global Positioning System (DGPS) with a base station in San Francisco Bay. The position of the towed vehicle was determined using an ORE Trackpoint II acoustic range and bearing system and a transponder mounted on the towed vehicle. Using a direction-sensing hydrophone assembly mounted on a bracket over the side of the vessel, the system acoustically measured the distance and the bearing from the vessel to the transponder on the towed vehicle. The navigation computer used this information, combined with measurements of the vessel's bearing from its gyrocompass and position from DGPS, to calculate the position of the towed vehicle. The PLUMES Data Acquisition System (DAS) recorded this position with the rest of the PLUMES data.

Operationally, the most significant problem was obtaining samples of suspended sediment. It was thought that a separate vessel (that is, other than
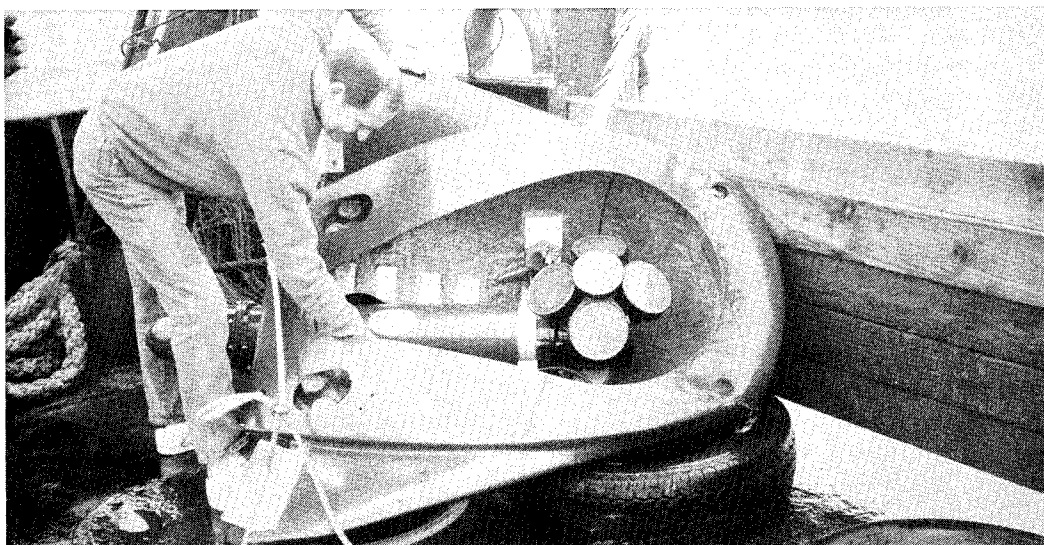
Figure 1. PLUMES in towed vehicle

the one with PLUMES), dedicated solely to obtaining water samples, could successfully obtain them from within the plumes. The second ship was equipped with a Niskin bottle rosette water sampler to take suspended sediment samples. The sampling system had twelve 1.7-L (nominal) sample bottles, a CTD, and a transponder. After the position of an acoustically measured plume was established by DGPS and acoustic data, the ship with the sampler was directed to the position where the plume was predicted to be at the time of the sampling.

This procedure was not successful for several reasons, however. First, the plumes had relatively small horizontal extents and were rapidly advected by the current. Second, the time required to get on-station and lower the water sampling system to sequential depths to obtain samples was generally unpredictable and lengthy compared with the plume movement.

A second operational procedure, which proved more successful, was one in which the ship moved in directly behind the barge and lowered the sampling system as the barge discharged material. However, this made it difficult for the ship with PLUMES to get into position to monitor the discharge.

Current Data Processing Procedures

The BBADCP in PLUMES measures the speed and direction of the water flowing through its acoustic beams and processes it to produce vertical profiles of current velocities. The profiles are composed of measurements in up to 128 horizontal slabs of water out to its maximum range of 35 to 50 m. The measured current velocities are relative to the sensors (that is, "ADCP-referenced" velocities). In shallow water, the system can also measure its own velocity over the bottom and calculate the water current velocities relative to the bottom ("earth-referenced" velocities). In deep water, the position data from the navigation system must be used to calculate the

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earth-referenced velocities of the BBADCP, from which earth-referenced current velocities can be calculated. Towed-vehicle velocities calculated from the raw position data recorded by PLUMES are too erratic to use for processing the current data. As a step in the processing, the towed vehicle position data were put through a backward/forward smoothing process, and the output was recorded in special navigation files.

The first step in processing the current data is to use a program called BBLIST to produce ASCII files of ADCP-referenced velocity data from the raw PLUMES binary data files recorded by DAS. BBLIST is a RD Instruments program available from the company for a five-beam BBADCP system. BBLIST corrects the directions for the magnetic variation, using a value entered by the user. There is one profile for each data "ensemble," which for the San Francisco monitoring program was one profile every 4 to 9 sec, but typically every 6 sec. The output files from BBLIST are input to a program called BBVEL, which was produced under the DRP.

The velocity data files produced by BBLIST have no information in them regarding the depth range of the profile. Depths must be determined from the CTD data in the raw PLUMES data file. BBVEL uses the current speed and direction data files produced by BBLIST, raw PLUMES data files, navigation files of smoothed towed vehicle position data, and a CTD calibration file to produce earth-referenced current velocity profile files referenced to the measured depth of the towed vehicle. In the case of the San Francisco data, each profile was the result of two acoustic signals (or "pings") from the BBADCP, with the returned signals from the pings processed in 1-m depth cells.

To obtain consistent results, it is was necessary to impose some reasonable selection criteria and to do some averaging. The criteria were that data were processed for stretches along the ship and towed vehicle tracklines where (1) the towed vehicle's heading was nearly the same as the ship's, (2) the towed vehicle was towed at a relatively constant depth, and (3) the ship's speed and course were steady. Average velocities were then calculated for these stretches by vector averaging the currents at each depth, using data from all the ensembles along the stretch of trackline that met the criteria. This resulted in averages representing 280 to 770 sec, with maximum standard deviations of approximately 7 cm/sec for speed and 25 deg for direction.

CTD Data Processing Procedures

During the San Francisco monitoring program, PLUMES recorded updated CTD data every 15 sec. Each update is for a single depth, which is the tow depth. The towed vehicle is normally towed over a narrow range of depths for a period of time and then lowered to another depth, where it is again towed over a narrow range of depths. Over the course of the program the system was towed at many depths, and the CTD data (recorded in multiple raw PLUMES data files) covered the full range of depths at which the system was towed. If the seawater properties are relatively uniform horizontally and

do not vary too much with time, as was the case off San Francisco, a single profile, which is representative of the location and time of the monitoring, can be assembled from the data stored in files. This is the function of a program called CTDDAT. CTDDAT uses multiple raw PLUMES data files and a CTD calibration file to produce single average profiles of water temperature, salinity, and density. CTDDAT was developed under the DRP.

Backscatter Intensity Processing Procedures

The backscatter intensity for the fifth beam needs to be corrected for spreading and absorption losses as described in *Dredging Research Technical Notes* 1-16. A program called BAKINT uses PLUMES data files and the average water properties profile produced by CTDDAT to produce a file of backscatter intensities corrected for these losses. BAKINT also puts the OBS reading in the output file with each ensemble of acoustic backscatter data. The depth of the towed vehicle is calculated by BAKINT using the CTD data and a CTD calibration file. For shallow water, the depth is fixed at 1 m. The position at which the data were taken is recorded in the output file, by BAKINT, using the smoothed towed vehicle position data.

A plot of backscatter intensity data from the San Francisco monitoring program, produced using one of the BAKINT output files, is shown in Figure 2. The figure shows a color-coded representation of relative backscatter intensity below the towed vehicle for the fifth beam. The greater the relative counts, as shown on the right of the figure, the greater the backscatter intensity. Off San Francisco, values of relative backscatter intensity were recorded for 96.75 m below the system; however, if the intensity was below the noise level, no color was printed.

Suspended sediments and background scatterers increase the backscatter intensity, so the signal can move in and out of the noise, producing the patchy pattern shown in Figure 2 near the maximum range of the system. The back-scatter intensity is shown in the figure at the correct depths (given in meters on the left of the figure), based on the value stored in the output file by BAKINT. The positions of the towed vehicle, from the BAKINT output file, were used to display the relative backscatter intensity data at the correct horizontal positions. The distance along each track in meters, and the positions of the end points of the track, in latitude and longitude, are shown at the bottom of the figure. Because the track was not always straight, the along-track distance was longer than the distance between the beginning and end points of the data. This distance in meters is given in the upper right-hand corner of the figure.

Figure 2 shows a level crossing of a plume at approximately 1,300 m along the track, at a depth of about 260 m. The plume is clearly distinguishable in this figure, 5.5 hr after the disposal operation that created it. At this time, the plume was approximately 900 m wide.

The work of Lohrmann and Huhta (in preparation) and Ogushwitz (1994) has shown that the relationship between the acoustic backscatter intensity and

the suspended sediment concentration can be studied using a Rayleigh scattering model. Under the DRP, a program called CONCEN has been developed which calculates suspended sediment concentrations by applying the Rayleigh Scattering model and the sonar equation as described in *Dredging Research Technical Notes* 1-16. The program can be applied to field data in cases where the grain-size distribution in a plume is known and can reasonably be assumed not to change or where the changes can be calculated.

CONCEN uses the BAKINT output files, a grain-size distribution file, a BBADCP calibration file, the average water properties profile produced by CTDDAT, and a background intensity file to produce a file of concentrations for each ensemble processed. The program is experimental and has not been used on the San Francisco data because a calibration for the BBADCP used in the monitoring program is not available.

Summary

Ten dredged material disposal operations were monitored in deep water off the coast of San Francisco, and plumes were successfully tracked for more than 6 hr. The operational techniques described in this technical note worked well with the exception of the water sampling procedure, as noted. A suite of data processing programs for processing PLUMES data has been developed under the DRP and is available for field use.

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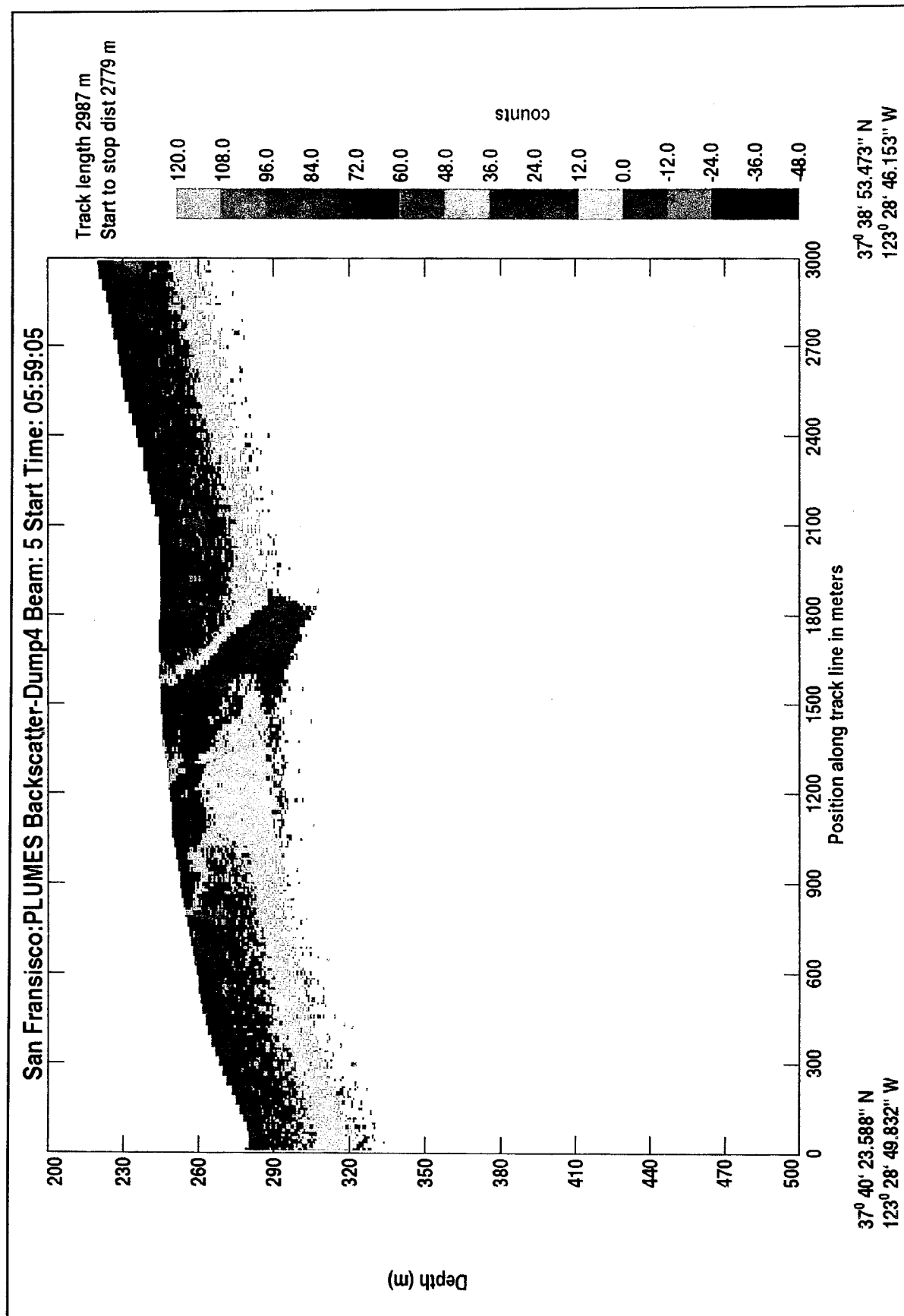
Figure 2. Acoustic backscatter intensity transect